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Probability of occurrence and habitat features for oriental bittersweet in an oak forest in the southern Appalachian mountains, USA

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Abstract

Oriental bittersweet (*Celastrus orbiculatus*), an introduced vine from southeast Asia, has become a serious threat to native forests in the eastern United States. It is typical of many exotic species in that quantitative ecological relationships are unavailable for assessment or management. We devised a rapid survey technique useful for hazard rating and modeled the probability of occurrence of oriental bittersweet in relation to environment, competition, and disturbance in stands of deciduous hardwoods in mountainous terrain. Oriental bittersweet was present on 39% of the study area, which has been managed by the selection system of silviculture and was recently disturbed by hurricane-force winds. Bittersweet was significantly associated with (1) topographic variables indicative of mesic environments, (2) density of midstory arborescent vegetation, (3) overstory canopy gaps, (4) past silvicultural harvests, (5) overstory canopy composition, and (5) scarification of the forest floor. Search distance from plot center to the first individual of bittersweet was significantly less ($P = 0.04$) on mesic than xeric sites. We developed a logistic regression model with five significant ($P < 0.05$) variables that classified correctly 87% of the sample plots. Variables in the model are biologically interpretable and indicate that the probability of occurrence of oriental bittersweet increases with (I) overstory canopy not dominated by oaks (*Quercus* spp.). (2) scarification of the forest floor, (3) concavity of the landscape around the site, (4) wind disturbance, and (5) increasing elevation. Using an independent data set from the same study area, the model classified correctly 88% of sample plots. Land management options in forests, where oriental bittersweet is present, are broadest on dry sites where its probability of occurrence is lowest and its growth response resulting from release should be least. Although herbicides can be effective in a program of intensive control, because of its biological characteristics we suggest that oriental bittersweet will present an increasing problem to land managers throughout the eastern United States. Published by Elsevier Science B.V.

Keywords: Disturbance; Exotic species; Hazard rating; Moisture regimes; Oriental bittersweet; Wild turkey

1. Introduction

Oriental bittersweet (*Celastrus orbiculatus* Thunberg. (Celastraceae)), a deciduous, woody vine native to southeast Asia, is a threat to native forests in the eastern United States. Its biological characteristics of shade tolerance, rapid growth response upon release from shading, prolific and consistent annual seed production with high viability and germination, and adaptation to a wide range of suitable environments (Patterson, 1974; Dreyer, 1988). These characteristics combine to make oriental bittersweet (hereafter, bittersweet) highly competitive with native vegetation

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and potentially difficult to manage in forests that are subject to recurrent natural or managed disturbance.

Since its introduction as an ornamental in the northeastern United States around 1860, bittersweet has spread to 33 states by 1974 (Patterson, 1974). Its classification as a weed in much of the eastern United States indicates its undesirable characteristics when it becomes naturalized (Dreyer, 1988). Bittersweet has favorable ornamental qualities, particularly its colorful and abundant fruit, which increases the likelihood that people will continue to contribute to expansion of its range. Seeds are believed to be disseminated primarily by birds (Stoll et al., 1980; Dreycr, 1994) that consume the leathery capsule consisting of three to five seeds, which ripens in the fall. Optimum seedbed conditions for bittersweet seed germination have not been reported. The introduced species is often mistaken for American bittersweet (*C. scandens* L.) a relatively rare native vine that is not a serious competitor with natural vegetation (Dreyer et al., 1987).

Bittersweet, also known as round-leaved and Asiatic bittersweet, is not widely naturalized in the southern Appalachian mountains except in isolated populations. Significant populations occur in parts of the Great Smoky Mountains National Park and near Asheville, NC, where it is particularly conspicuous along interstate highways. Only recently have we become aware of the species and its associated problems in the Pisgah National Forest near Asheville (McNab and Meeker, 1987).

Aside from information on its geographical distribution (Patterson, 1974; Dreyer, 1994), general biological characteristics (Patterson, 1974), and response to herbicides (Dreyer, 1988; Hutchinson, 1992), little quantitative information is available on the ecology of bittersweet in forested environments, particularly in relation to moisture regimes and various types of forest disturbances. Most knowledge on bittersweet has been descriptive and little information is available that can be used for development of quantitative models of its occurrence on landscapes. For bittersweet as well as many other introduced species ecologists lack understanding of how invaders spread through native communities, although disturbance appears to play a major role (Bergelson et al., 1993). Canopy and soil disturbance caused by windstorms may provide natural conditions favorable to its colonization of new sites (Greenberg and McNab, 1998).

The purpose of our research was to test the hypothesis that bittersweet occurrence is differentially associated with moisture regimes that can be easily quantified and accurately modeled. Specific objectives of this study were to (1) quantify occurrence of bittersweet in relation to environmental conditions and disturbance, and (2) develop and test a model that quantifies the relationship between oriental bittersweet and variables associated with its occurrence. A related objective was to develop methods for rapid field assessments that could be used for hazard rating as a part of silvicultural stand prescriptions or at broader landscape scales. We presumed this rapid assessment method might have application for determining the status of other exotic species, though we have not yet tested this.

2. Methods

2.1. Experimental site

Our study was conducted in the Bent Creek Experimental Forest (35°30′N, 82°37.5′W), a field research facility of the US Department of Agriculture, Forest Service, about 16 km south of Asheville, NC, USA (Fig. 1). This mountainous watershed of 2400 ha, which ranges in altitude from 600 m in a broad intermountain basin to 1100 m along two primary ridges, is characterized by many smaller watersheds formed by secondary and tertiary ridges. Annual temperature averages 12.8 °C. Precipitation averages about 120 cm annually and is evenly distributed throughout the year. Geologic formations primarily consist of Precambrian gneisses and schists. Soils on most sites are generally deep (>100 cm) and predominantly acidic <5.5 pH.

Dominant arborescent vegetation consists of a high canopy (>30 m) of deciduous hardwoods. Dominant canopy species on middle to upper slopes are xerophytic oaks: black (*Quercus velutina* Lam.), chestnut (*Q. prinus* L.), scarlet (*Q. coccinea* Muenchh.), and white (*Q. alba* L.). The overstory of lower slopes and valleys is typically dominated by mesophytic species: yellow-poplar (*Liriodendron tulipifera* L.), sweet birch (*Betula lenta* L.), and

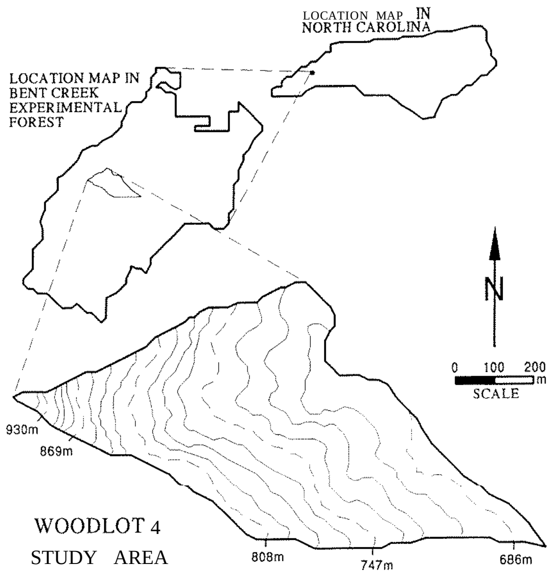

Fig. 1. Location and topography of the 43.3 ha study area in woodlot 4, Bent Creek Experimental Forest, Asheville, NC, USA.

sometimes northern red oak (*Q. rubra* L.). Red maple (*Acer rubrum* L.) is common on all sites. Midstory species consist of red maple, sourwood (*Oxydendrum arboreum* (L.) DC.) and flowering dogwood (*Cornus florida* L.). A high (2-S m) shrub layer, where present, is dominated by two species: mountain laurel (*Kalmia latifolia* L.) on dry sites and rhododendron (*Rhododendron maximum* L.) on moist sites. Ground cover consists of huckleberries (*Gaylussacia* spp. HBK.) and blueberries (*Vaccinium* spp. L.) on dry sites, and herbs and ferns on mesic areas. Canopy coverage is generally >90% on all but the driest sites. Bittersweet occurs throughout the experimental forest.

We studied a 42.2 ha tract of mountainous terrain consisting of the valley and slopes formed by two smaller ridges extending from a larger ridge (Fig. 1). The tract (woodlot 4) is mostly east-facing and has topographic features similar to the surrounding experimental forest. The woodlot has been actively managed for timber production since 1946 using the selection method of silviculture. Della-Bianca and Beck (1985) present more detail on the woodlot and results of long-term timber management. The presence of bittersweet was not conspicuous at the time of the previous harvest in 198.5. Woodlot 4 was selected for study primarily because of the presence of (1) a well-designed system of permanent sample points established in the early 1970s to monitor effects of timber resource management on arborescent vegetation, and (2) disturbance associated with silvicultural operations.

2.2. *Study design*

We used a system of 58 permanent transects randomly spaced one to seven chains (20-140 m) apart that were previously established from seven baselines throughout the study area. A total of 198 sample plots, equivalent to about 5/ha, had been previously located at one to three chains (20-60 m) intervals along the transects. The circular sample plots were 10 m in radius (314 m’). We obtained two independent data sets from the system of transects and plots: (I) a development data set for characterization of the spatial distribution of bittersweet and building prediction models was derived from the 198 plots, and (2) a validation data set was obtained from a plot located at the beginning of each transect where it intersected the base line. The validation set consisted of 58 plots and simulated routes of travel through the woodlot in a manner that could be used when applying the prediction model to classify sites for risk assessment.

Data of two types were recorded at each sample plot: (1) quantitative environmental and biological variables that defined the moisture regime and competing vegetation, and (2) qualitative variables that described disturbance to the vegetation. We measured topographic variables primarily associated with moisture regimes: elevation (m), aspect (cosine transformation of degrees azimuth), slope gradient-a continuous, objective measure of inclination of land surface from horizontal determined by hand-held clinometer (%), landform index (McNab, 1993)-a continuous, objectively measured index value associated with mesoscale landforms (e.g. small values indicate convex ridge landforms and larger values are associated with concave cove landforms) on which the sample plot was situated, and terrain shape index (McNab, 1989)-a continuous, objectively measured index value of the plot’s land surface configuration (e.g. negative values indicate convex plot surface shapes and positive values indicate concave plot surface shapes). Arborescent vegetation was quantified by determining basal area of overstory and midstory canopy levels using a 2.5 m^2/ha factor prism (Grosenbaugh, 1952). We also determined if the canopy was dominated by oaks, most of which tend to be xerophytic species (i.e. black, chestnut, scarlet). as a means of simply, quickly, and objectively assessing the prevailing site moisture regime by means of a single categorical variable.

We recorded disturbances to the canopy and forest floor that could have influenced the light regime or soil on the sample plot and affected presence of bittersweet. The following types of disturbance were recorded as present or absent: (1) harvest of trees for silvicultural purposes as indicated by presence of stumps or logging residues, (2) road of any type used for logging, skidding or access, (3) obvious wind damage resulting in tree uprooting and stem breakage resulting from Hurricane Opal in October 1995, (4) other damage apparently from ice, insects, disease or vines, or (5) scarification of the litter layer, apparently by foraging animals.

We devised a method of recording presence of canopy gaps viewed from the plot center that was similar in concept to using an angle gauge for determining plotless tree basal area (Grosenbaugh, 1952). A canopy gap was recorded if its size exceeded the area of our outstretched hand with fingers joined (approximately 10 cm x 15 cm or 0.015 m^2) held overhead at arm's length and perpendicular to our line of vision. The minimum gap area defined by this method ranged from about 9.4 to 84.4 m^2 at canopy heights ranging from 10 to 30 m, respectively. Our method of determining presence of a canopy gap was not precise because gaps were typically irregular. The method could be applied quickly and with consistent results; however, it was considered an exploratory variable.

Field data were collected in mid-April following bud break and leaf expansion of bittersweet adequate for its identification. Its presence could be quickly and consistently determined, even for small seedlings (<5 cm high), because bittersweet initiated growth before almost all other species. Beginning at the center and continuing in concentric bands, each plot was searched for presence of bittersweet. We recorded distance (nearest 0.1 m) from the plot center to the first encountered bittersweet plant (Kent and Coker, 1997), (1) to test if mean area searched varied by moisture regime and (2) to estimate plant density. We used the method of Batcheler (1971) for truncated distance samples to estimate density of bittersweet, without correction for bias based on nearest neighbor measurements and assumed random sample distributions (Engeman et al., 1994). We did not confirm estimated density by counting bittersweet stems on plots because to do so would have required additional time and would likely have been inaccurate on plots of high stem density. Although precise estimates of stem density by plot would have provided data for study of population dynamics, it was not needed to satisfy our objectives. Our field inventory and data collection technique required about 5 min/plot, which seemed reasonable for extensive. landscape-scale surveys.

2.3. Data analysis

The association of bittersweet with each of the continuous topographic and vegetative variables was determined using t-tests. Simple tests of independence between presence or absence of bittersweet with occurrence or nonoccurrence of the categorical variables were made with 2 x 2 contingency tables with Yate's correction for continuity of chi-square (Zar, 1996). Following logic of species/area curves, search distances were summarized by 10 classes of successively doubled area ranging from 0.615 to 3 14 m^2 for xeric or mesic moisture regimes, defined by presence or absence of canopy oaks. We tested for significant differences of search distance between moisture regimes using a t-test. Data summarization was done with SAS (SAS Institute Inc.. 1985).

We used maximum likelihood logistic regression to determine the interrelationships of all variables on the occurrence of bittersweet. Our model was

$$P = \frac{\exp(\boldsymbol{b}_1\boldsymbol{X}_1)}{1 + \exp(\boldsymbol{b}_1\boldsymbol{X}_1)} \quad (1)$$

where P is the estimated probability of bittersweet occurrence; $\boldsymbol{b}_1$ the vector of regression coefficients; $\boldsymbol{X}_1$ the vector of independent variables; exp the base of the natural logarithms.

The logistic model had advantages for our study because (1) limits of probability between 1 and 0 allow it to match occurrences of the species, and (2) it is well suited and robust for indicator variables with non-normal or binary distributions (Hosmer and Lemeshow, 1989). The logistic model has been applied in vegetation research to estimate dominance probabilities of northern red oak regeneration (Loftis, 1990), and prediction of occurrence of sparsely occurring species (Wiser et al., 1998). We used STATA (Stata Corp., 1997) for development of the logistic model and used the likelihood ratio test at the 0.05 level of probability to indicate variables for inclusion in the model.

We validated the logistic regression model using an independent set of 58 plots excluded from model development. Predicted bittersweet occurrence was assigned as absent if estimated probability was ≤ 0.5 or as present if >0.5. Actual presence of bittersweet was compared with predicted using the validation data set. We used a 2 x 2 chi-square test to compare results of the validation with chance. Misclassification is described in terms of Type I (bittersweet absent but predicted as present) and Type II (bittersweet present but predicted as absent) errors (Zar, 1996); Type II errors are potentially the most serious in development of occurrence models for invasive species.

3. Results

3.1. Bittersweet–environment correlations

Presence of bittersweet was associated with higher elevations, steeper slope gradients, concave (sheltered) landforms and reduced levels of midstory basal area. Mean values of environmental variables were about equal for the development and the validation data sets (Table I). The largest difference between the two data sets was for terrain shape index, which indicates plot land surfaces were slightly more convex in the validation data set. This is likely because many base lines, and hence the validation plots, were established along ridges while the development data set was from plots mostly perpendicular to ridges and parallel to contours.

Bittersweet was present on 77 (38.8%) of the 198 plots sampled (Table 2). The t-tests indicated that mean values of all continuous variables except aspect and overstory basal area were significantly different ($P \leq 0.005$) on sites where bittersweet was present compared to where it was absent. Bittersweet was significantly associated ($P \leq 0.005$) with four categorical variables: oak canopy, canopy gap, silvicultural harvest, and scarification (Table 3). The two variables of highest significance indicate that bittersweet was generally absent where an oak canopy occurred (5 1 .0% of plots) and where scarification did not occur (58.6%). The relationship of wind disturbance on bittersweet occurrence was weak ($P < 0.157$). Disturbance associated with roads or other types had little effect on bittersweet occurrence.

In an unplanned comparison, the presence of bittersweet was examined in relation to other species occurring on the plots. The strongest relationship was a perfect negative correlation between bittersweet and mountain laurel, which occurred on 44 (22.2%) of the 198 sample plots. Mountain laurel is an evergreen, low-growing (up to 2 m tall) shrub that typically occurs on sites with topographic characteristics that suggest a drier than average moisture regime.

The distribution of bittersweet varied by site moisture regime (Fig. 2). On 50% of sample plots where bittersweet was present in mesic regimes, the

Table I
Characteristics of topographic and arborescent vegetation variables in the development and validation data sets from woodlot 4, Bent Creek Experimental Forest, Asheville, NC, USA

Variable	Development (I? = 198)		Validation (n = 58)	
	Mean	Range	Mean	Range
Elevation (m)	749	680–942	756	676–936
Aspect (°)	90	I-360	121	11–359
Gradient (%)	36	5–91	31	4–70
Landform index	0.207	0.106-0.322	0.185	0.06X-0.3 I I
Terrain shape index	0.005	−0.142–0.218	-0.022	−0.160–0.138
Overstory BA (m^2/ha)	14.0	2.5–27.5	15.2	2.5–30.0
Midstory WA (m^2/ha)	9.3	0–22.5	8.6	(r-IS.0

Table 2
Mean values (S.E.) of topographic and arhorescent vegetation variables where oriental bittersweet (*Celastrus orbiculatus* Thunberg.) was present or absent on plots in the development data set in woodlot 4, Bent Creek Experimental Forest, Asheville. NC, USA

Variable	Oriental bittersweet		Probability $(P) > |t|$ [a]
	Present (n = 77)	Absent (n = 121)	
Elevation (m)	762.83 (7.6)	740.42 (4.1)	0.00s
Aspect (cosine)	1.70 (0.03)	1.64 (0.04	0.311
Gradient (%)	39.58 (2.0)	33.38 (1.1)	0.004
Landform index	0.23 (0.004)	0.19 (0.003)	0.001
Terrain shape index	0.02 (0.008)	-0.01 (0.004)	0.001
Overstory basal area (m^2/ha)	14.51 (0.58)	13.70 (0.48)	0.283
Midstory basal area (m^2/ha)	7.9s (0.56)	10.04 (0.47)	0.005

[a] Under the assumption of equal variances for the two populations

first plant was found within an area of about 15 m^2 (radius 2.18 m) around the plot center. A larger search area was required for plots in xeric moisture regimes, indicating that fewer plants present. The mean distance of the first bittersweet plant from the plot center was 3.13 m on plots without an oak canopy compared to 4.77 m on plots beneath an oak canopy, a small but significant $= 0.04$) difference. On 22% of all plots where bittersweet was present, the first plant occurred within a search distance of 1 m (Fig. 2 inset).

Table 3
Chi-square matrixes of percent associations between absence or presence of oriental bittersweet (*Celastrus orbiculatus* Thunberg.) and nonoccurrence or occurrence of various categorical variables in woodlot 4. Bent Creek Experimental Forest, Asheville. NC, USA

Variable	Oriental bittersweet		Chi-square probability
	Absent ($n = 121$)	Present ($n = 77$)	
Canopy composition			
No oaks (79)	10.1	29.x	0.001
Oaks (119)	51.0	9.1	
Canopy gap			
No gap (1 0h)	37.9	15.7	0.004
Gap (92)	23.3	23.3	
Silvicultural harvest			
No harvest (96)	25.8	25.8	0.002
Harvest (102)	35.3	13.1	
Rood			
No road (172)	54.6	32.1	0.302
Road (26)	6.6	6.6	
Wind damage			
No damage (174)	55.6	32.3	0.157
Damage (24)	5.6	6.6	
Other disturbance			
No disturbance (196)	61.1	37.9	0.292
Disturbance (2)	0.0	1.0	
Scarification			
No scarification (152)	58.6	1x.2	0.001
Scarification (46)	2.5	x.7	

3.2. Model development

The combined influence of five variables, as expressed in the logistic regression model (Table 4), was significantly ($P < 0.0001$) related to the presence of bittersweet. The two most significant variables were presence of an oak canopy and scarification (***P*** < 0.0001) followed by landform index and wind disturbance ($P = 0.005$). Elevation was marginally significant (***P*** $= 0.04$). Collectively, these variables

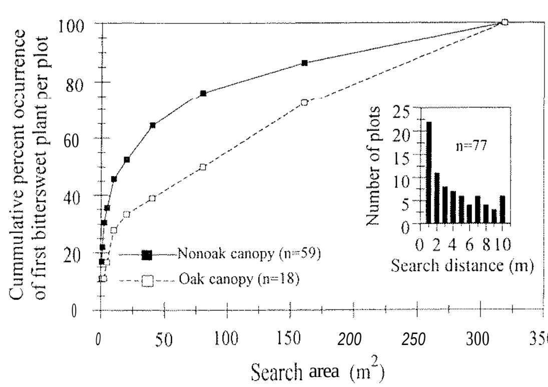

Fig. 2. Cumulative percent occurrence of bittersweet in relation to area searched by two ova-story canopy types. Inset illustrates the distribution of the first occurrence of bittersweet by linear distance from the plot center.

Table 4
Logistic regression model and associated statistics for probability of occurrence of oriental bittersweet (*Celastrus orbiculatus* Thunberg.) in woodlot 4, Bent Creek Experimental Forest, Asheville, NC, USA

Independent variable	Unstandardized coefficient	S.E.	Probability (*P*) > chi-square	Standardized coefficient
Constant	-14.3710	4.8675	0.0032	
Oak canopy	-3.0898	0.5969	0.0001	-0.X36.1
Scarification	3.875 1	0.7336	0.000 1	0.9045
Landform index	24.2402	7.4699	0.0012	0.5529
Wind damage	2.3301	0.8286	0.0049	0.4203
Elevation	0.0127	0.0063	0.0439	0.3874

have a pseudo R^2 of 0.56 and signs of the coefficients are interpretable. The model indicates the probability of bittersweet increases on a site if an oak-dominated canopy is absent, wind disturbance and forest floor scarification are present, and with increasing landform index (indicative of sheltered, concave landforms) and elevation.

Model performance using the development data set resulted in correct classification of 87.3% (e.g. 32.8 + 54.5%) of the sample plots (Table 5). Total misclassification of 12.7% was about equally divided between Type I (6.6%) and Type II errors (6.1%). Performance of the model by varying three of the more important indicator variables (landform index, oak canopy, and wind disturbance) is illustrated in Fig. 3. Probability of bittersweet occurrence approaches zero at low values of landform index (low values indicate sites with ridge landforms), in the presence of a canopy dominated by oaks, and the absence of wind disturbance. The opposite situation (high landform index, absence of an oak canopy and presence of wind disturbance) produces predicted probabilities of bittersweet approaching one. Other combinations of variables provide similar estimates of probabilities of bittersweet occurrence, such as replacing effects of an oak canopy with presence of forest floor scarification.

Table 5
Classification matrix of actual and predicted percent (*N* plots) occurrence of oriental bittersweet (*Celastrus orbiculatus* Thunberg.) by application of the logistic model (Table 4) to the development data set in woodlot 4, Bent Creek Experimental Forest, Asheville, NC, USA

Predicted occurrence	Actual occurrence		
	Present	Absent	Total
Present	32.x (6.5)	6.6 (13)	39.4 (78)
Absent	6.1 (12)	54.5 (10X)	60.6 (120)
Total	38.9 (77)	61.1 (121)	100.0 (19X)

3.3. Model validation

We applied the model to the validation data set consisting of 58 plots and the resulting predictions of bittersweet occurrence were significantly better than by chance alone ($P < 0.0001$). The model predicted correctly the presence or absence of bittersweet on 87.9% of the plots (Table 6) and performed almost identically to results of the development data set. Prediction errors were about evenly distributed between Type I (6.9%) and Type II (5.2%). Although both error types were small, the most serious error is Type 11, which incorrectly predicts the absence of bittersweet. Our validation was informative but not

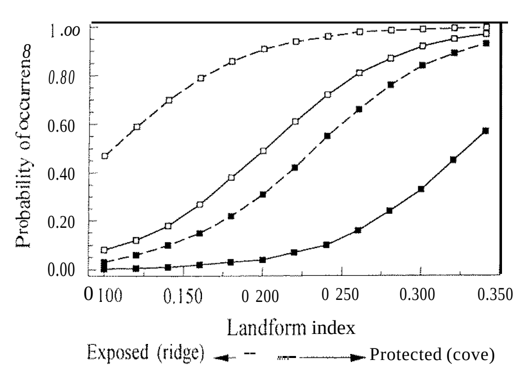

Fig. 3. Probability of occurrence of bittersweet based on the logistic model (Table 4) in response to varying levels of landform index, occurrence (■) or nonoccurrence (□) of an oak canopy, and occurrence (- -) or nonoccurrence (—) of wind disturbance.

Table 6
Classification matrix of actual and predicted percent (*N* plots) occurrence of oriental bittersweet (*Celastrus orbiculatus* Thunberg.) by application of the logistic model (Table 4) to the validation data set in woodlot 4. Bent Creek Experimental Forest, Asheville, NC, USA

Predicted occurrence	Actual occurrence		
	Present	Absent	Total
Present	18.9 (11)	6.9 (4)	25.9 (15)
Absent	5.2 (3)	69.0 (40)	74.1 (43)
Total	24.1 (14)	75.9 (44)	100.0 (58)

rigorous; although an independent data set was used, it originated from the same area in which the model was developed. Our results indicate that the model may be suitable for hazard rating elsewhere in the southern Appalachian mountains, although this needs testing.

4. Discussion

We found the presence of bittersweet was associated with topographic variables that typically indicate greater site moisture availability, such as concave landforms. In addition, canopy species composition was a highly significant indicator variable and suggests that moisture gradients are a primary factor resulting in the differential occurrence of bittersweet. Reports of bittersweet in other areas (Patterson, 1974; Dreyer, 1994) have provided little information on the site moisture status.

The relationship we found between elevation and bittersweet was probably an artifact of the data set. Most wind disturbance from Hurricane Opal occurred above 870 m elevation on a steep slope in the extreme western portion of woodlot 4 (Fig. 1). This part of the study area is along a road where bittersweet likely was present before the occurrence of hurricane disturbance. Observations at other areas in the experimental forest, from 600 to 1 100 m, suggest that elevation is not a strong factor affecting the occurrence of bittersweet. Logic of our finding that bittersweet was associated with wind disturbance but not with silvicultural harvest is unclear because overstory basal area was reduced by both types of disturbance. A possible explanation is that bittersweet was not present in the stand at the time of the previous harvest, but was present later, at the time of wind disturbance. Our casual observations during data collection revealed that bittersweet seedlings were present in 3 of 11 (27.3%) pits caused by hurricane-related windthrow of trees 3 years previously, all of which were on dry, oak-dominated sites. Future silvicultural disturbance may have the same effect on occurrence of bittersweet that we found for wind disturbance, which resulted in increased probability of occurrence.

The impacts of competing vegetation and disturbance on presence of bittersweet are varied. Basal area of the arborescent overstory had little effect on presence of bittersweet, although there was a slight inverse relationship for midstory basal area. Canopy gaps, as quantified by our simple assessment method. had little direct relationship with bittersweet occurrence in the presence of other indicator variables. We thought it possible that reduced basal area, canopy gaps and disturbance should allow more light to reach the forest floor, resulting in greater survival and presence of bittersweet. Clement et al. (199 1) reported that germination of bittersweet seeds was greater in low light conditions than in increased light. Patterson (1975) reported that bittersweet seeds germinated in light intensity of <2% of full sunlight and responded quickly to release by achieving maximum CO_2 uptake in only 8 days. Our results suggest that availability of light is not an important factor affecting presence of bittersweet.

Bittersweet vines emerged from winter dormancy and began stem elongation several weeks before the arborescent overstory. We observed that many bittersweet seedlings from 0.2 to 0.5 m height had experienced periodic dieback of the stem terminal followed by resprouting. Patterson (1975) reported that tip ends of bittersweet stems are typically killed by onset of freezing temperatures in the fall and although not reported, susceptibility of seedlings to cold damage could be influenced by their location in relation to canopy gaps. Bittersweet seedlings in an understory with an assumed regime of low light intensity appear to respond as Loftis (1990) observed for some red oak seedlings beneath an overstory, which follow a pattern of top dieback and resprouting of the rootstock.

Our application of the point density relationship for truncated distance samples (Batcheler, 197 1) resulted in an estimate of approximately 425 bittersweet stems per ha for mesic sites and 255 stems per ha for xeric sites. These density estimates were not corrected for bias and should be used primarily for evaluating intensity of control activities or setting management priorities. We recommend employing a correction for bias when using the point-density relationship to estimate densities, which would increase accuracy of estimates.

Our observations of increased bittersweet occurrence with disturbance (scarification) of the forest floor, primarily on plots with mature trees and few shrubs, suggests that mineral soil is beneficial to bittersweet seedling establishment. Although we did not observe the source of the forest floor scarification, characteristics of the disturbance (Hewitt, 1967) and other observations in the Bent Creek Experimental Forest (personal communication, T. Harshbarger, May 1999) suggest foraging by wild turkeys (*Meleagris gallopavo* L.). Our results are supported by Miller et al. (1999) who found that turkeys in central Mississippi preferred habitats with open, mature hardwood sawtimber stands. Additional study is needed to establish a causal relationship between turkey foraging and bittersweet occurrence.

5. Conclusions and management considerations

Results of our study indicate the probability of oriental bittersweet occurrence in an area typical of the southern Appalachian mountains is greater in mesic environments and where the overstory canopy and the forest floor have been disturbed. Our regression model should be used primarily for hazard rating in areas where oriental bittersweet is known to occur. Although this study was conducted at a single location in the mountains of western North Carolina, the general results regarding bittersweet's habitat preferences may be applicable over a broader area of the Southern Appalachian mountains with similar environmental conditions. Additional validation of our preliminary model is desirable over a broader geographic area.

If land managers need occurrence information on exotic species in general and bittersweet in particular then techniques of this study are applicable. The rapid inventory system we devised in a small study area can easily be adapted for larger, landscape-scale inventories that may include other invasive species that can occur in a forested environment. Such species include Japanese honeysuckle (*Lonicera japonica* Thunb.), princess tree (*Paulownia tomentosa* (Thunb.) Sieb. and Zucc. ex Steud.), and tree of heaven (*Ailanthus altissima* (P. Mill.) Swingle). This system would likely not be useful for a species such as kudzu (*Pueraria montana* var. lobata (Willd.) Maesen and S. Almeida), which occurs as extensive patches in openings, particularly beside roads.

The most difficult part of any field inventory will likely be the unbiased location of sample plots (Batcheler, 1971). The simple point-distance density function we used should be adequate for calculation of index values for setting management priorities. However, stem counts should be made on sample plots if accurate, unbiased density estimates are required.

Managers of lands where bittersweet presents a threat should consider slowing the spread of this species by aggressively controlling isolated patches. Techniques such as hand pulling and clipping can be effective means of control during early stages of invasion when stem densities are low. Herbicide formulations of Roundup® (glyphosphate) or Crossbow® (2,4-D and triclopyr) have been shown to be effective for bittersweet control (Dreyer, 1988; Hutchinson, 1992). Drawbacks to use of herbicides include detrimental effects on nontarget vegetation, hazards associated with contact by applicators, and increased expenses for the product, application, and safety equipment. Prescribed burning could be a treatment to reduce above ground coverage on some sites based on studies with Japanese honeysuckle (Barden and Matthews, 1980), a widespread exotic vine in the southeastern US with characteristics similar to those of bittersweet. Prescribed fire, however, could be difficult to control in mountainous terrain, presents risk of damage to other vegetation, adverse effects on air quality, and does not kill the root system. Use of herbicides or fire should be carefully evaluated by the manager who must consider the social, economic, and ecological implications of treatment or no-treatment options.

[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the US Department of Agriculture of any product or service.

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